Pictorial History of the Los Angeles Aguaduct

PICTORIAL HISTORY OF THE AQUEDUCT

Compiled and Produced by
Times-Mirror Printing & Binding House

Historical Sketch
OF THE
Los Angeles Aqueduct

With MAP
PROFILE *and*
ILLUSTRATIONS

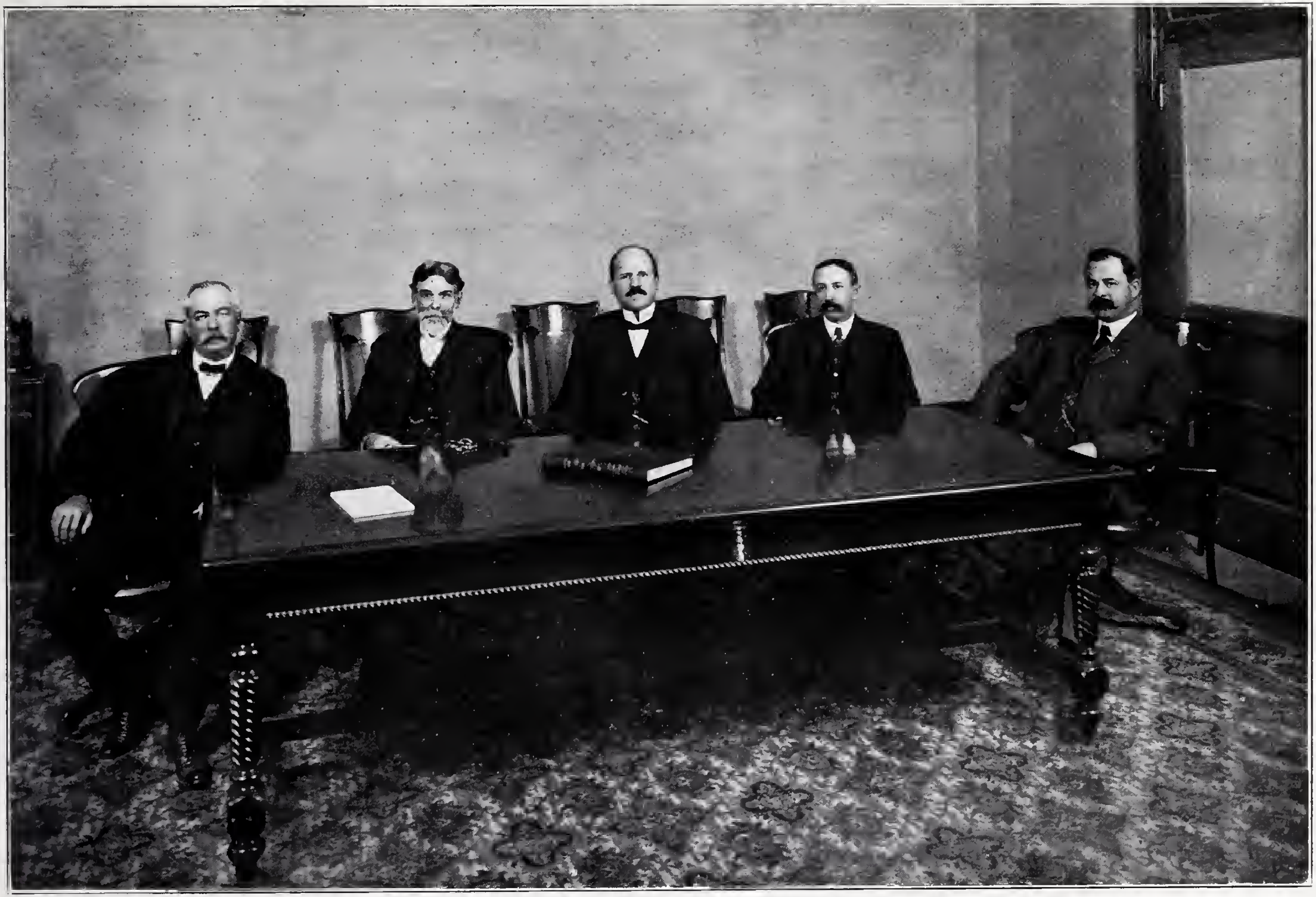
Text by Allen Kelly — *Photos by Bledsoe*

Plates by American Engraving & Electrotype Co.

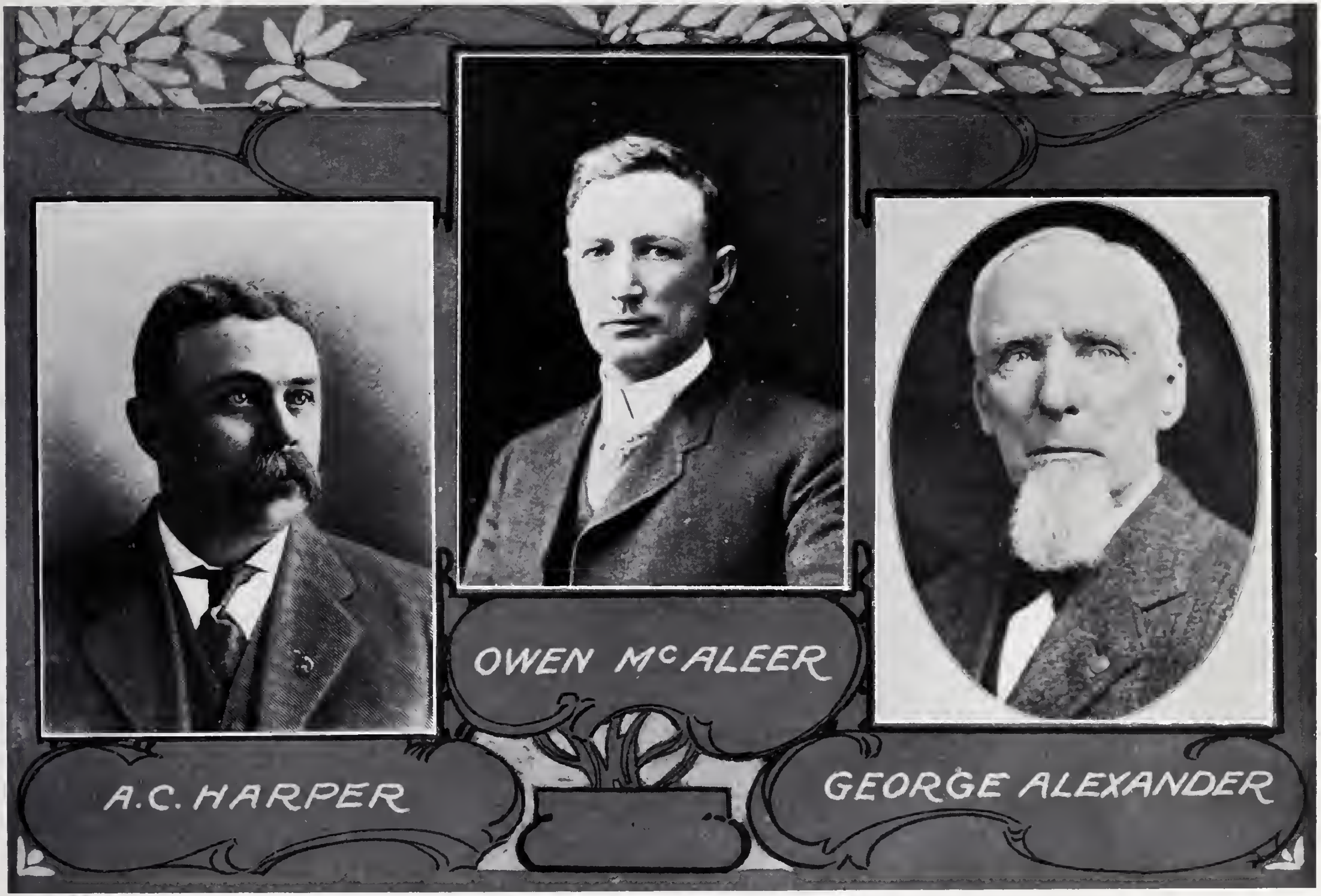
1913

William Mulholland

Fred Eaton



Water Board That Initiated Aqueduct Project.



Mayors of Los Angeles During Period of Aqueduct Building.

Members of Board of Public Works, 1907 to 1913.

Members of Advisory Committee.

THIS is the story of a dream that came true; of an idea audaciously conceived and splendidly realized. It is an outline sketch of the history of the Los Angeles Aqueduct, the great conduit of concrete and steel that brings a river across hundreds of miles of desert and through mountains to make possible the building in California's sunny southland of one of the wonder cities of the world.

Less than a dozen years ago the vision of the dreamer was told in these words:

"A drop of water, taken up from the ocean by a sunbeam, shall fall as a snowflake upon the mountain top, rest in the frozen silence through the long winter, stir again under the summer sun and seek to find its way back to the sea down the granite steeps and fissures. It shall join its fellows in mad frolics in mountain gorges, singing the song of falling waters and dancing with the fairies in the moonlight. It shall lie upon the bosom of a crystal lake, and forget for a while its quest of the ocean level. Again it shall obey the law and resume its journey with murmurs and frettings; and then it shall pass out of the sunlight and the free air and be borne along a weary way in darkness and silence for many days. And at last the drop that fell as a snowflake upon the Sierra's crest and set out to find its home in the sea, shall be taken up from beneath the ground by a thirsty rootlet and distilled into the perfume of an orange blossom in a garden of the City of the Queen of the Angels."

The construction of the aqueduct that brings the waters of Owens River across 250 miles of desolate and rugged country to the city of Los Angeles has set a new standard of public service for American municipalities. No other public work at all comparable in magnitude to the aqueduct has been accomplished within the limits of cost and time fixed by the engineers in their first estimates. It is not an exaggeration to say that the builders of the aqueduct have established a world's record of efficiency and economy. They promised that the work should be done in five years and water delivered at the San Fernando reservoir at a cost of $23,000,000. They began work in 1908, and they have brought the water to San Fernando in 1913 at a cost within the original estimate.

For several years the men upon whom rested the responsibility of providing the city of Los Angeles with sufficient water for her people sought in vain for sources of permanent supply equal to prospective demands. The necessity for additional supply was made plain to the Water Commissioners in 1904, when for ten days in July the daily consumption of water exceeded the inflow into the reservoirs by nearly four million gallons. Excessive consumption was checked by the use of meters, and some small additions to the supply were obtained from wells, but the rapid increase of the city's population made such relief only temporary, and the board was confronted by a problem of serious proportions. The board imposed upon Engineers Wm. Mulholland, J. B. Lippincott and O. K. Parker the task of gathering data and finding a solution of the problem, and their report in 1905 showed the hopelessness of seeking relief in any watershed south of the Tehachepi. There is water under the ground of all the coastal plain in which the city stands, but it is not an inexhaustible reservoir, and the drafts made upon the underflow by the pumps of thousands of farms and orchards were found to be steadily lowering the plane of saturation. To take more water for the city from the underground reservoir would stop the development of the surrounding country and set a limit to the growth of Los Angeles. The engineers were forced to the conclusion that nowhere in the basin south of the Tehachepi range and west of the San Bernardino could Los Angeles obtain any considerable flow of water without taking it from the lands which produce the wealth of Southern California. They said in their report to the board:

"It must be constantly borne in mind that within this valley of Southern California the prosperity of any single community depends largely upon the prosperity of the surrounding communities. No city, no county, no enterprise stands alone in this regard. The city of Los Angeles will not build wisely for the future if it builds at the expense of any of the contiguous agricultural areas. With but one-fourth of the irrigable acreage of the coastal plain now under irrigation and abundant evidence available that the ground waters, which furnish the greater portion of the supply used in this irrigation, are already being subjected to over-draughts, it is evident that the city cannot permanently enter the field and subject the basin to further extensive draughts, which must continually increase as our city expands, without seriously interfering with the growth of one of our most promising agricultural regions."

In estimating the future needs of the city, the engineers assumed a rate of growth based upon the average for the ten preceding years and predicted an increase from 200,000 in 1905 to 250,000 in 1912 and 390,000 in 1925. Assuming a reduction of average consumption of water, by the use of meters, to 150 gallons a day for each inhabitant, the city would require in 1925 a supply of 90 second feet or more than 58,000,000 gallons a day, which is more than double the minimum flow of the Los Angeles River and ten second feet in excess of the recorded maximum flow at the narrows.

The city, however, failed to keep within the limits of the growth diagram drawn by the engineers, and by 1910, as shown by the Federal census, its population had reached the figure set by them for 1918, viz: 319,000. According to the diagram in the report of the engineers, the city would have a population of half a million in the year 1936. As a matter of fact, it reached that stage of growth in 1913. Fortunately, a seven-year period of abundant rain brought the flow of the Los Angeles River up from the forty second feet of 1905 to 70 second feet in 1911, nearly doubling the city's supply from that source. Heavy draughts were made by pumps upon the ground waters, lowering the water plane from six to nine feet, and the per capita consumption was decreased by the extended use of meters to 138 gallons a day. Because of the series of wet seasons and the resort to the temporary expedient of robbing the agricultural lands of the coastal plain of their ground waters, the city escaped a water famine during the period of its wonderful growth, but there was no margin of safety, and the lowering of the ground water plane confirmed the judgment of the Water Board and its engineers in seeking other sources of supply.

Early in 1905, a solution of the water problem was suggested to Water Superintendent Mulholland by Fred Eaton, who had been City Engineer and Mayor of Los Angeles. Mr. Eaton had interests in Inyo county, and for many years had been making extended trips through the valley of Owens River, which lies between the Sierra Nevada and ranges of desert mountains on the eastern State line. In the valley Mr. Eaton had seen vast floods of water pouring wastefully from the Sierra snowfields into Owens Lake, a dead sea of the Inyo desert, where hundreds of thousands of years of evaporation and condensation had produced a saturated solution of soda salts, and he had wished that those floods could be made available to the great city which he saw growing in the Southland.

On his journeys to and from the valley, Eaton studied the country with the eye of an engineer, and he saw that in some past geologic period the river flowing for 100 miles along the eastern foot of the Sierra had been a great torrent, swinging around the end of the range and pouring into the basin of the Mojave desert. Volcanic action had cut off the flow by throwing a barrier across the south end of Owens Valley and forming the enclosed basin in which the lake lies. But the barrier was low, and below it the old stream route was still open to within a few miles of the Southern California plain, the only obstacle being the range of mountains north of Los Angeles.

EATON'S DREAM

Confident that a constantly descending route for the river could be found, Eaton made surveys from Owens Valley to the mountains north of the city, and proved the practicability of his dream. And then he waited for the time when Los Angeles should realize her need and be ready to consider the bold undertaking of bringing water 250 miles across the desert and piercing a mountain range to make way for the conduit. He waited many years, never doubting that the city of his dreams would become a reality, and when the Pueblo awoke, found itself a city of measureless possibilities and began to take thought of providing for its future, Eaton confidently laid the foundation of his great water project by making contracts for the purchase of lands controlling water rights and reservoir sites on Owens River and taking options from riparian owners.

Eaton felt so certain that Owens River was the only available supply adequate to the needs of the city that he formed his plans to carry out the project as a private enterprise in case the city should hesitate to take up a work of such magnitude. He figured that he could supply the city with water and electrical power, and make the enterprise pay, and he found capitalists who agreed with him and were eager to take up the project. Others also had seen the possibilities of profit in such an enterprise, and one of the electric power companies had made plans for bringing water and power from Owens River to Los Angeles, but had been checked by the inauguration of an irrigation project by the Reclamation Service.

Land bought by Eaton included the reservoir site of the irrigation project, designed to reclaim

desert public lands in the upper end of Owens Valley. Against a private enterprise, the Reclamation Service could exercise the right of condemnation. As against a municipality seeking water for a large urban population, the government would not persist in its project, its policy being to promote the good of the greatest number. Eaton therefore laid his plans before Superintendent Mulholland and suggested that the city take over his contracts and options and carry out the project as a public enterprise, which would be aided instead of opposed by the Federal government.

Mulholland had never thought of Owens River as a possible solution of the problem which had been turning his hair gray, for he knew nothing of the river or the country through which a conduit would have to pass. With Eaton he made a trip over the route and a general examination of the hydrography of Owens Valley, and was impressed by the possibilities of the scheme.

Then he studied the problem in detail, going over the line alone and making a rough survey with an aneroid and a pocket level, keeping the purpose of his frequent trips into the desert a secret from all but the Water Board until he had satisfied himself that he had found a feasible route for an aqueduct. He plotted an approximate line upon the detailed topographic maps of the U. S. Geological Survey and determined the lengths of open canal, covered conduit, tunnels and siphons that would be required, located reservoirs and calculated quantities of material to be moved and placed, and made an estimate of cost that was confirmed later by thorough instrumental surveys and minute calculations. He then made a report to the Water Board and outlined an aqueduct and reservoir system, which he estimated would cost, including the purchase of land and water rights, about $25,000,000.

Mulholland realized that the Board would rely upon his judgment as an engineer and that upon him would rest the responsibility of committing the city to a stupendous enterprise. If he should make a serious error in his judgment of the engineering practicability of the project or in his estimate of cost, professional ruin would befall him. It required sure knowledge of conditions, genius in designing plans and great courage in accepting responsibility. Mulholland "made good" in all. He recommended Eaton's proposals to the Board, and the Board had the courage and confidence to accept them and to use its own funds in taking over Eaton's contracts and options before making the project public.

The Board of Water Commissioners was composed of John J. Fay, Fred L. Baker, J. M. Elliott, M. H. Sherman and Wm. Mead.

In April, 1905, Messrs. Fay and Elliott, accompanied by Mayor McAleer, City Attorney Mathews, and Messrs. Eaton and Mulholland, made a visit to the Owens River Valley, for the purpose of further investigating the water conditions existing there, and of considering a proposal from Mr. Eaton to sell and transfer to the city his options and contracts for the purchase of lands and water rights along the Owens River.

RIGHTS IN OWENS VALLEY SECURED

After carefully considering all available information concerning sources of water supply, sufficient for the needs of the city, both in and outside of Southern California, the Board became thoroughly convinced that the Owens River afforded the only adequate supply that could be obtained by the city at a cost which it would be justified in incurring. Having reached this conclusion, the Board entered into a contract with Mr. Eaton for the acquisition of the property embraced in the proposal submitted by him, and devoted the available funds of the Water Department to this purpose. This property included most of the riparian lands for a distance of about forty miles along the river above Owens Lake, in Inyo county, and a reservoir site in Long Valley, in Mono county.

The proceedings of the Board were conducted with the utmost secrecy, in order to prevent speculators from anticipating the city in securing the property desired. The contracts made it necessary to provide for about $700,000 in order to consummate the purchase of this property and to return to the Water Revenue Fund the amounts advanced by the Board.

In August, 1905, on his return from the Owens River Valley, Mr. William Mulholland took into his confidence Mr. J. O. Koepfli, President of the Chamber of Commerce, and stated to him that he had found in the Owens River Valley a source of supply that would furnish Los Angeles with all the water that it would ever need. President Koepfli immediately took the matter up with the Board of Directors of the Chamber, and in conjunction with other commercial bodies sent a special committee, consisting of H. C. Witmer, M. Lissner and Fred A. Hines, to the Owens River Valley to make a

personal investigation, especially with reference to the quality of the water. This committee obtained samples of the water and had them analyzed both at the State University and in Los Angeles.

As soon as this investigation was completed an election was called to vote $1,500,000 in bonds for the purchase of land and water rights in the Owens River Valley, the Chamber of Commerce strongly urging the people to vote the bonds and the following report of a special committee was given to the public.

"By careful investigation we have endeavored to secure all the information possible in connection with the proposed plans. We have conferred with the city officials, the water board and with disinterested engineers and contractors. We have examined maps and government reports and have joined with other commercial bodies in sending a special committee consisting of H. C. Witmer, M. Lissner and Fred A. Hines to the Owens River Valley to make a personal investigation, especially with reference to the quality of the water, of which a number of analyses were made by different chemists.

"From this inquiry the conclusion of your committee may be thus summarized:

"First—It is imperatively necessary to secure a new water supply if the development of this city is to be continued.

"Second—The Owens River Valley is the only source that promises a permanent supply that will be sufficient.

"Third—There is an ample supply for our needs, and the quality of the water is satisfactory.

"Fourth—There are no difficult engineering problems presented in building the conduit needed. It is a large but simple proposition.

"Fifth—The estimates of cost of construction are very liberal and the total outlay will probably come well within the estimate made by Mr. Mulholland, engineer of the Water Department.

"Sixth—While there will undoubtedly be more or less litigation as in all enterprises of this character, we believe that the rights sought to be acquired by the city can be successfully maintained and defended.

"In connection with the above conclusions we desire to express our satisfaction with the skill and marked ability displayed by those officials of the city who have had charge of its interests. A project of this kind conducted by a municipality usually fails or becomes a matter of great expense by reason of premature knowledge of the plans.

"We believe that they were sufficiently informed on all material points involved in the enterprise to justify the action taken by them. They do not expect to expend any more money than is necessary to conserve the city's interest until they shall have secured the approval of the entire plans by disinterested experts of the highest character.

"We heartily approve the entire project and recommend that the bonds be voted."

(Signed)

W. J. WASHBURN,
WILLIS H. BOOTH,
A. B. CASS,
WILLIAM D. STEPHENS,
JACOB BARUCH,
FRED A. HINES.

The Owens River project was made known to the people of Los Angeles in July, 1905, and was received with enthusiastic approval as the only practicable and adequate answer to the most vital question confronting the city. The Water Board asked the city to issue bonds for $1,500,000 for the purchase of lands and water and the inauguration of work on the aqueduct, and on September 7, 1905, by a vote of 10,787 to 755, the citizens of Los Angeles approved the bonds and endorsed the Owens River project.

In November, 1906, the city employed three of the most eminent hydraulic engineers in the United States to examine and report on the project. The consulting engineers were Frederick P. Stearns, president of the American Society of Civil Engineers and member of the Isthmian Canal Commission; John R. Freeman, the greatest specialist in hydraulics in the country; and James D. Schuyler, builder of the largest dams in the West, and an engineer of wide experience.

The Consulting Board made its report on December 25, 1906, showing that a supply of 20,000 miners' inches of water could be obtained from Owens Valley, and that the cost of building an aqueduct to bring it to San Fernando, including purchases of land and water rights, would be $24,485,600. The engineers said: "We find the project in every respect feasible, and that it involves no great difficulties of engineering or construction other than those arising from mere length and distance." They also declared the water to be of good quality for domestic use, and in conclusion the greatest engineers in America paid this high compliment to Eaton, the dreamer, and Mulholland, the designer: "We find the project admirable in conception and outline and full of promise for the continued prosperity of the city of Los Angeles." The engineers estimated the time of construction, after the sale of bonds, as five years.

APPROVED BY THE PEOPLE

In 1907, the question of issuing bonds for $23,000,000 for the construction of the Owens River Aqueduct was submitted to the people by the City Council, and a campaign of education was carried on by the civic and commercial bodies and the press. The Chamber of Commerce, the Merchants and Manufacturers Association and other organizations investigated the project thoroughly, the Mayor and Council scrutinized it in detail, engineers studied it and reported their conclusions, and on June 13, 1907, the people of Los Angeles endorsed the project by voting in favor of the bond issue. The vote was in the ratio of ten to one.

From the time of the first issue of bonds, the aqueduct project ceased to be under the jurisdiction of the Water Board and came under control of the Board of Public Works, which was composed in 1907 of James A. Anderson, Albert A. Hubbard and David K. Edwards. However, because of the great public confidence in the Board of Water Commissioners and their special knowledge of the subject, the Board of Public Works consulted and co-operated with the Water Board, and all important actions were taken as the result of joint conferences. An Advisory Committee was appointed by the two boards to handle details and organize the working force of the aqueduct. This committee consisted of the president of the Board of Public Works, president of the Water Board. Chief Engineer Mulholland, Assistant Chief

Engineer J. B. Lippincott and Attorney W. B. Mathews. Some changes in the personnel of the Board of Public Works occurred during the progress of the work. President Anderson retired and was succeeded by Gen. Adna R. Chaffee, and Mr. Edwards was succeeded by W. M. Humphreys. In 1912, Gen. Chaffee and Mr. Humphreys retired and Lorin A. Handley and Edward Johnson took their places.

In obtaining rights of way and control of surplus water in Owens Valley, the city was aided materially by Director Walcott of the Geological Survey, Chief Engineer Newell of the Reclamation Service, Chief Forester Gifford Pinchot, U. S. Senator Frank P. Flint and other Federal officers. The Reclamation Service abandoned its Owens Valley project in favor of the city, and the Federal officers named joined with a committee of the Chamber of Commerce in presenting the matter to President Roosevelt and securing his approval of a bill confirming the city's right to use such public lands as it might require. A special right of way act was passed by Congress in June, 1906, granting free right of use to the City of Los Angeles of all public lands required for canals, reservoirs and power plants in Inyo, Kern and Los Angeles counties. President Roosevelt, in order to still further assist the city, withdrew by executive order all lands in bulk along the line of the proposed aqueduct and in Owens Valley which might be of possible use to the city and which might be filed upon by individuals or corporations prior to the time when the city could complete its surveys and file definite rights maps.

PLAN OF THE AQUEDUCT

The general plan of the aqueduct, as outlined by Mulholland and approved by the Advisory Board of Engineers, subject to such modifications and changes of location as might be found advisable during progress of the work, was as follows: an intake on Owens River about thirty-five miles north of the point where the river empties into Owens Lake; an open canal of 900 second feet capacity through Owens Valley, 23 miles unlined and 37 miles lined with concrete, to Haiwee reservoir at an elevation 200 feet above the level of Owens Lake; Haiwee reservoir, to accumulate and store the waters of the river and of intercepted streams flowing down the east side of the Sierra Nevada, having a capacity of 63,800 acre feet or 20,000,000,000 gallons; from Haiwee to Little Lake, 15 miles of lined and covered conduit of 410

second feet capacity; Little Lake to Indian Wells, 24 miles of conduit, tunnels and siphon pipes; Indian Wells to Red Rock summit, 20 miles of conduit, flumes and siphon; Red Rock through the "bad lands" of Jawbone Canyon to the Mojave desert, nearly nineteen miles of tunnels, siphons and conduit; through the Mojave desert to the west end of Antelope Valley, 68 miles, mostly of concrete conduit; reservoir at Fairmont to regulate delivery of water through pressure tunnel; Elizabeth Lake tunnel, 25,000 feet; power drops in San Francisquito Canyon; tunnels, siphons, flumes and conduit to San Fernando reservoir, 15 miles; total, 225.87 miles, exclusive of reservoirs and power water ways.

A vast amount of preparatory work had to precede aqueduct construction, and that was begun in the fall of 1907. It was believed by the engineers that the time of completion of the aqueduct would be controlled by the driving of the longest tunnel, and, therefore, the portals of the Elizabeth tunnel were opened simultaneously with the beginning of preparatory work along the line, but with that exception no permanent work was begun until October, 1908. Crews were organized and camps established in September, but construction dates from October 1, 1908.

In the first eleven months twenty-two miles of tunnel were driven, sixteen miles of cement conduit completed, four miles of open canal in Owens Valley dug, and a rate of progress established that would have brought the water into the San Fernando reservoirs in the fall of 1912 had there been no delay in providing funds.

The hardest part of the work was tackled first, and it was done for less than the estimated cost, and in much less than the estimated time. The engineers might have concentrated their forces on the easier work of conduit building in the open country and made a spectacular showing in mileage for the first year, but they were not playing to the gallery.

Before work could be begun on the aqueduct, it was necessary to build roads and trails, power plants, telegraph and telephone lines and provide water supply for camps established along 150 miles of waterless desert. Expenditures for preparation were as follows:

Water investigation	$ 25,000
Preliminary engineering, etc	1,000,000
Real estate, water rights, etc	1,587,000
Cement mill	750,000
Roads and trails	155,000
Water supply	193,000
Power plants	110,000
Transmission lines	152,000
Telegraph and telephone lines	58,000
Total	$4,030,000

Included in this work were 215 miles of road, 230 miles of pipe line, 218 miles of power transmission line and 377 miles of telegraph and telephone line. Fifty-seven camps were established along the line of work, most of them in the mountains, and good roads made to reach them. Some of the roads challenge comparison with the finest mountain roads in California, and all of them are better than the stage roads existing in the desert before the city began its work.

The problem of transportation of material through the desert to construction camps between Mojave and Owens Valley was solved by the building of a branch of the Southern Pacific Railroad, known as the Nevada & California Railway, from Mojave to a junction with the narrow-gauge line in Owens Valley. The road is of standard gauge, laid with heavy steel, and is a permanent part of the Southern Pacific's system. It was built in accordance with a traffic agreement with the city and was completed in October, 1910. The city also built a temporary line about nine miles long from the main line into the Jawbone division by way of Red Rock. When this track had served its purpose, it was taken up and sold for $30,000, a part of the material being bought by the U. S. Government and used in the building of levees on the lower Colorado.

Materials for making cement were found on the Cuddeback ranch five miles east of Tehachepi on the main line of the Southern Pacific. The city bought 4300 acres of land, covering limestone quarries,

clay deposits and deposits of tufa, and built a cement mill of a designed capacity of 1000 barrels of Portland cement a day. This plant is known as the Monolith mill. It was found that the grinding of tufa with the Portland cement doubled the volume and improved the quality of the concrete, producing a material identical with the cement used by the Romans in their imperishable work. Tufa cement does not acquire hardness as rapidly as straight cement, but at ninety days it exceeds straight cement in strength and continues to improve with age long after the time at which Portland cement reaches its maximum of hardness and strength. In addition to the output of the Monolith mill and the tufa grinding plants at several points on the line of the aqueduct, the city used 200,000 barrels of cement bought from the Riverside mill. More than a million barrels of cement were used. Made into ordinary concrete, this would be sufficient to build a six-foot sidewalk from Los Angeles to New York, or a wall around Manhattan Island ten feet thick and forty feet high.

In the acquisition of water rights and for operation, maintenance and protection of the aqueduct, the Board of Public Works bought 124,929 acres of land in the drainage basin of Owens River, 4300 acres near Tehachepi, 69 acres for yards at Mojave and 5818 acres for reservoir sites; total, 135,116 acres, exclusive of canal rights of way. This is an area three times the size of the island of Catalina and double the total area of the city of Los Angeles.

DRIVING THE TUNNELS

World's records for speed, efficiency and economy were made by the tunnel drivers on the aqueduct. The American record for hard-rock tunnel driving—604 feet in one month—is blazoned above the south portal of the Elizabeth Lake tunnel. This bore through the mountain, 26,870 feet in length, 10 by 12 in diameter, and having a capacity of 1000 cubic feet of water per second, or 27,000,000 gallons an hour, was driven and lined for two-thirds of the estimated cost and in two-thirds of the time allotted by the Board of Consulting Engineers. The excavation work was in charge of John Gray at the north end of the tunnel and W. C. Aston at the south end. The average progress for the two headings was 22.1 feet, or a little better than 11 feet per day for each end.

When this tunnel work was started, it was estimated that a reasonable progress for each end would be eight feet per day with three eight-hour shifts, and a bonus schedule was adopted by the Board of Public Works which provided that each man working in the tunnel would receive a bonus of 40 cents for each foot that this schedule was exceeded. This bonus was paid in addition to the regular wages, the men receiving these wages whether the bonus schedule was exceeded or not, and the bonus being distinctly a reward for extra exertion. The effect of the bonus was to increase the daily wage of the men about 30 per cent. and to decrease the cost of driving per foot from 10 to 15 per cent. There was a further saving to the city in expedition of the work and in early release of equipment for use elsewhere.

From the South Portal, 13,500 feet of tunnel were driven and from the North Portal, 13,370 feet. The average rate of progress at the South Portal was 11.11 feet per day; at the North Portal, after the connection was made through to the shaft, the average progress was 13.65 feet per day. From the portal to the end of the section driven from the north end, including delays on account of shaft and cave-ins, the average progress was 11 feet per day. The average progress for the two headings for the 1215 days' work was 22.1 feet, or a little better than 11 feet per day for each end. The connection was made of the two headings on February 28, 1911, after the expiration of forty months of work. (The time which the Board of Engineers estimated as necessary to complete this was five years.) The center line of the tunnel met within 1⅛ inches and the grade checked within ⅝ inch. The total cost per foot for the driving of the tunnel, including administration, equipment, surveys, etc., but not lining, was $44.80, and the saving over the estimate of the Board of Engineers was about half a million dollars.

A noteworthy record was made in driving the Red Rock Tunnel. This tunnel is in an indurated sand or soft sandstone, and is 10,596 feet in length. Excavation was started on May 27, 1909, and completed January 24, 1910. The maximum excavation run made from one heading was in August, 1909, when an advance of 1061 feet was made in 31 days. This is the most rapid advance of a single tunnel heading ever made in one month. The lining of the tunnel was started in February, 1910, and completed in September, 1910. This two-mile tunnel, therefore, was excavated and lined in sixteen months. The average cost of excavation per foot was $8.26 and for lining was $6.12.

The Red Rock tunnel crew raced with the Swiss drivers of the Loetchberg tunnel for the world's record, and won it. In August, 1909, the Swiss broke their own previous record by driving 1013 feet, working with four air drills in one heading. Tom Flannigan's crew at Red Rock, working with hand drills in one heading, drove 1061 feet. The hard rock men in the Elizabeth tunnel raced with the government crew on the Gunnison tunnel, and beat them. There are 111 tunnels, aggregating 43 miles in length, in the aqueduct. Some of the heaviest and most difficult work on the line was in the Jawbone division, which comprises a stretch of very rough mountain and canyon country intervening between the Indian Wells Valley and the Mojave Desert. In this division lies the mass of deeply eroded sandstone and indurated drift known as the Bad Lands. When John R. Freeman looked over that formidable jumble of wrinkles in Mother Earth's face he said, doubtingly, to Mulholland: "That is a very rough and difficult country for canal digging."

"It is rough on top," replied Mulholland, "but we are not going to dig on top. The aqueduct will go under all that, and when you are underground the character of the surface is negligible. When you buy a piece of pork you don't have to eat the bristles."

Freeman saw the point, and was not disturbed further by the rough appearance of the country.

THE "BRISTLES ON THE PORK"

The aqueduct passes through the mountains of Jawbone division in a series of tunnels of varying length, connected by short stretches of conduit, and crossing the deeper and wider canyons in inverted steel siphons. The Jawbone division consists of 12.07 miles of tunnel, 7.47 miles of conduit, .04 of a mile of flume, and 2.2 miles of steel siphon. The Jawbone siphon is the most imposing piece of work on the aqueduct. Its total length is 8136 feet and it varies from 7 feet 6 inches to 10 feet in diameter. The steel plate of which this pipe is built is 1⅛ inch thick in the heaviest section. The maximum head on the pipe is 850 feet, and its total weight is 3243 tons. It is the most noteworthy pipe in the United States.

In 1908 the Board of Public Works requested bids for the construction of this division by contract, exclusive of the steel siphons. Seven bids were received from responsible firms. On the advice

of the Chief Engineer all were rejected and the work was undertaken by day labor, A. C. Hansen being placed in charge. The work covered by the specifications was done in half the time estimated by the bidders, and the saving over the lowest bid received was about $700,000.

The longest siphon on the aqueduct is the pipe crossing Antelope Valley. It is 21,767 feet in length, and up to heads of 80 feet is built of concrete, the remaining 15,597 feet being steel pipe. The concrete and steel pipes are both 10 feet in diameter. The maximum head on this siphon is 200 feet, and the weight of the steel is 3324 tons.

There are 98 miles of covered conduit south of the Haiwee reservoir. The covering was not included in the original estimate of the Board of Engineers, but it was a part of Mulholland's plan. Mulholland never had any idea of leaving the conduit through the desert uncovered. He said he would save enough on the tunnels to pay for the cover, and he did. The covering cost more than a million dollars.

RESERVOIRS

The first reservoir on the line is at Haiwee, seven miles south of Owens Lake. It is located in a pass and is formed by two dams seven and a half miles apart. The elevation of the high water in the Haiwee reservoir is 3764 feet. The area of the water surface is 2100 acres and the capacity of the reservoir is 63,800 acre feet, or enough water to run the full capacity of the aqueduct for 80 days.

The length of the North Haiwee dam is 1890 feet, the maximum height 46 feet, and width on top 20 feet, and it contains more than 200,000 cubic yards of earth. The maximum depth of water against this north dam is 36 feet.

The South Haiwee dam is 1523 feet long and 91 feet high, and contains 559,750 yards of earth. The dam has slopes of 2½ horizontal to 1 vertical on each side, with a top width of 20 feet, and a maximum width at its base of 450 feet. At this point on account of the depth of water, a core-wall was put down to bedrock, a maximum depth of 120 feet, at a cost of $70,000.

The outlet from the reservoir is through a tunnel 1193 feet long and 10 feet in diameter in the clear, which has been driven through the west abutment. There is a submerged canal in the reservoir

site 700 feet in length from the north portal of this tunnel to the lowest point in the reservoir. The gate-tower is a concrete structure 80 feet in height, and 21 feet outside diameter. It contains large gates placed at different elevations to regulate the outflow of water.

The Fairmont reservoir is intended not only as a safeguard in the shape of a storage supply 200 miles from the intake, but also as a means for regulating the hourly fluctuation of water through the power plants located below, to meet peak load conditions. The capacity of the conduit into this reservoir is 420 cubic feet per second, but the outlet tunnel from the reservoir to the power plant has a capacity of 1000 cubic feet per second. This will permit the discharge of this large volume of water in the few hours of the day during which the maximum demand exists for electric energy, and the decrease of the flow of water to a minimum amount during the night hours when the demand for power is relatively small. The capacity of the Fairmont reservoir at the 3035 foot elevation is 7620 acre feet. The dam has a maximum center height of 115 feet and contains 607,114 cubic yards. It is built of earth with a concrete core-wall.

The Dry Canyon dam on the Saugus division is 528 feet long, has a center height of 61 feet and contains 140,000 cubic yards of earth. The Dry Canyon reservoir has a storage capacity of 1325 acre feet and its province is to regulate back to uniformity the irregular flow that may be discharged through the power plants.

The San Fernando reservoirs, into which the water is delivered from the aqueduct for distribution to the city and contiguous territory, have a storage capacity of 36,600 acre feet, or enough to furnish a full supply for a month and a half in case of breaks in the line above.

The city also owns a reservoir site in Long Valley in the northerly portion of the drainage basin of Owens River, having a tributary watershed of 391 square miles. If this reservoir should be constructed, the flow line would be at an elevation of 6810 feet, the area of its water surface would be 8686 acres, and its storage capacity would be 340,980 acre feet. This would call for a dam 520 feet long on top and 160 feet in height. A structure of this character would make this one of the most notable storage reservoirs in the United States. It may be found desirable to build this Long Valley reservoir when

the complete flow of the aqueduct has been utilized. In this event, its province would be to hold over a water supply from years of excessive flow for such years of drouth as may occur once in a generation.

A second great reservoir site is controlled by the city at a point about six miles north of the intake of the canal. This is known as the Tinemaha reservoir site. Its flow line would be at an elevation of 3887 feet. The area of its water surface would be 7074 acres, and its storage capacity would be 127,325 acre feet, with an earthen dam 40 feet high. This reservoir site has the advantage of being situated near the intake of the canal, and the city owns continuously both sides of the river from the dam site to the intake, thus offering protection from trespass any waters which might be discharged from it.

The capacity of the Long Valley reservoir would be sufficient to furnish a continuous flow of the full aqueduct for a period of 427 days, and the Tinemaha reservoir, with the height of dam given, for a period of 159 days.

In addition to this, eleven wells have been put down in the bottom lands of Owens Valley along the line of the canal, and ten of these have struck artesian water. This body of underground and artesian water in Owens Valley is about fifty miles in length, and is largely controlled by the city. This is a great underground reservoir.

WORLD'S RECORDS BROKEN

More than six million pounds of blasting powder were used by the builders of the aqueduct, and yet only five men were killed in accidents in underground work. This record is remarkable in contrast with the casualty record of the Catskill Aqueduct in New York, which shows 160 men killed and 1600 injured underground. The comparative freedom from accidents with powder in the Los Angeles work is not attributed wholly to superior skill and carefulness of the men having charge of blasting operations. It was due in a great measure to the use of the most perfect fuse obtainable regardless of cost. Only the highest quality of German fuse was used, and it was submitted to the most rigorous tests for accuracy of timing and for reliability; tests that the cheaper American fuse failed to meet.

The Aqueduct builders and the City of Los Angeles have established records that are worthy of being preserved in tablets of bronze. First is the record of the least loss of life in the dangerous work of tunnel driving. Then there are the records for speed in driving through hard rock, and records for eco-

nomical operation of machinery. For the first time in the history of American municipalities, public work of magnitude has been accomplished at a cost not exceeding the first estimate, and millions of public money have been expended without graft or suspicion of graft.

During the progress of the work, it was examined critically by the chief engineer of New York's great Catskill aqueduct, who had read of the Owens River project and was skeptical about the magnitude of the work. After the engineer had gone over the line, he said he was amazed at the courage and nerve of the men who went into the desert to find water, and at the courage of the people who undertook the work of bringing it to the city through such a forbidding region. He was impressed most profoundly by the success of a municipality in doing the work with its own force instead of by contract and doing it economically, efficiently and without graft.

The New York engineer was accustomed to the Tammany system, but he was not in sympathy with the almost universal belief that public work is inevitably extravagant and wasteful. He said the people could always get honest service when they really demanded it and were willing to trust their servants. He said the people of Los Angeles got honest service because they had the good fortune to find the right man and the good sense to trust him.

Efficient machinery is an important factor in expedition of construction, but the unprecedented speed and economy of work on the Los Angeles aqueduct were due to the men behind the machines. The creative genius and engineering skill of William Mulholland made the work possible and inspired the people of Los Angeles with confidence to undertake it. His sure judgment of character and capacity secured to the city the services of a remarkably efficient and enthusiastic corps of division engineers and superintendents, and to the interest and intelligent zeal of these men much of the success of the undertaking must be attributed. They were men who could be trusted to carry out the designs of the chief without having every detail explained or shown minutely in blue prints.

Mulholland's method was to leave the widest discretion to the man on the job, and he generally put the right sort of man on the job.

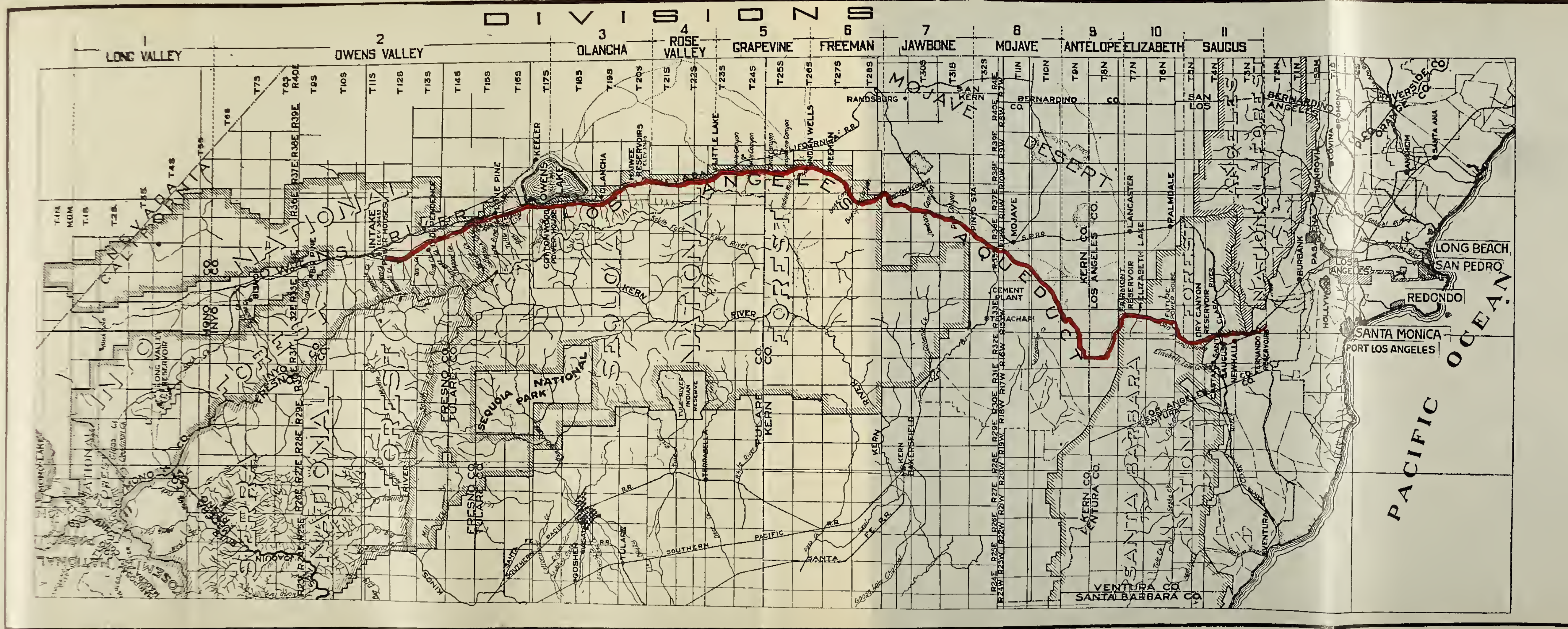
The remarkable efficiency records made by division engineers and superintendents of construction on the aqueduct attracted the attention of engineers and great contracting companies, and when

these men finished their work for Los Angeles, their services were in demand wherever big work was going on. An engineering company, having trouble in driving a difficult tunnel in Spain, engaged at a large salary one of the men who broke the record in the Elizabeth tunnel, and sent him to Barcelona to solve its problem. Another went to the Argentine on a big public work, and the man who made the record drive in the Red Rock tunnel went to the Catskill Aqueduct. All over the world, the capable builders of the Los Angeles Aqueduct are doing big work and making good on their well-earned reputations for efficiency.

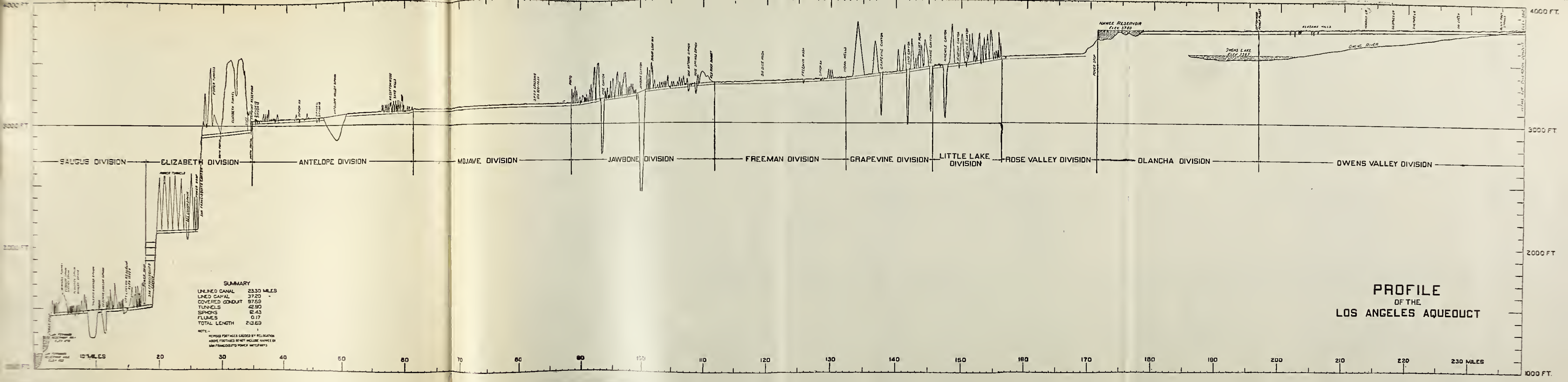
FINANCIAL

The fiscal year 1910-11 was marked by fluctuations in the monthly expenditures and rate of progress on the work. The condition of general financial depression in the spring of 1910 retarded the sale of bonds by the syndicate handling the aqueduct securities, and a serious shortage of funds occurred during the summer of 1910. The suspension of the work proved a very expensive experience. The dissolution of the splendid organization then assembled meant not alone the trouble of recruiting a new force, but also a distinct money loss in the necessity of slowly training the new men to the accomplishment of efficient service. The administration, or over-head charges, remained practically the same with a force of 1500 men in the field as with over 3000.

While the date of completion of the aqueduct was delayed only six months because of this interruption, the effective loss amounted to fully one year. This shortage was partially relieved by the advancement of funds from the Water Department, the purchase of one million dollars' worth of bonds by the New York Life and Metropolitan Life Insurance companies, and by the advancement of $1,326,000 from the aqueduct sinking fund by the Council, this advance being secured by aqueduct bonds. February, 1911, the bond syndicate again met its obligations by the purchase of the amount of aqueduct bonds provided for in their option. The effect of this financial situation was felt on the work. In May, 1910, there was expended $575,000 and 6.97 miles of conduit were excavated. In July the expenditures dropped to $321,000 and the progress was reduced to 3.08 miles. In October the expenditures were $320,000 and the progress was 2.94 miles of excavation and 3.30 miles of concrete lining. The work gradually expanded until May, 1911, when $346,000 was expended and 4.91 miles of aqueduct excavated.



MAP
OF THE
LOS ANGELES AQUEDUCT
AND ADJACENT TERRITORY
OCTOBER 1908
Scale in Miles



PROFILE
OF THE
LOS ANGELES AQUEDUCT

these n
going (
large s
to solv
record
builders
tions fo

T
progres
the sale
occurre
The dis
a new f
plishme
with a
V
terrupti
advance
by the
from th
ruary,
bonds
1910, th
dropped
$320,000
gradual

The aqueduct has been completed within the original estimated cost and without additional bonds or financial assistance; the finishing touches, repairs, clean up, etc., being paid from funds provided by sale of plant and equipment.

The work was really done for about two and a half millions under the estimate, as additional work as noted below was paid for out of the funds, which work was not contemplated by the Board of Consulting Engineers, nor included in the estimate of $24,500,000.

Placing cover on approximately 100 miles of the conduit, at an average cost of $12,500 per mile..	$1,250,000
Building larger and more expensive tunnels and providing storage reservoirs on account of requirements of Power Development..	650,000
Paying the Power Bureau an equitable share of the cost of the San Francisquito Tunnels.....	600,000
Total	$2,500,000

In addition to the above additional expenditure the aqueduct suffered considerable loss on account of the temporary shut-down in the summer of 1910, caused by financial stringency. At the time of the shut-down there were approximately 4000 men in the field, and in a few weeks the force had been reduced to less than 1000 men.

The loss of organization, decrease of efficiency and resulting increase of unit costs when the forces were reorganized, caring for plant and equipment temporarily idle, and the delay of the time of completion is conservatively estimated to have cost at least $250,000.

POWER PLANTS

Electrical power to drive dredges, excavators, drills, machinery in shops and cement mills, and to light the camps and tunnels, was developed in plants installed on Division Creek near the intake and on Cottonwood Creek near the lower end of Owens Valley. High voltage lines transmitted the power along the line to the mill at Monolith. Power for work in San Francisquito was taken from the Kern River line, which passes through the canyon.

In San Francisquito Canyon, two drops, aggregating 1500 feet, are to be used to develop about 47,000 horse power of electrical energy, from the sale and use of which the city may derive a large revenue.

In April, 1910, the city voted three and a half million dollars for the construction of power plants in the San Francisquito Canyon and elsewhere, and for the building of related electric works. The validity of the bonds was questioned, and the courts appealed to. This involved a delay in the building of the hydraulic works in the San Francisquito until the State Supreme Court should pass on the matter. A decision of the Supreme Court was rendered in June, 1911, sustaining the contentions of the city and establishing the validity of the bonds, and the work was begun under direction of the Public Service Board and not as a part of the aqueduct, although the conduit used for the generation of power will also be essential for the conveyance of the water to the City of Los Angeles as a portion of the aqueduct.

The capacity of the power plants that have been and may be installed along the line is as follows:

Division Creek	800	H. P.
Cottonwood Creek	8,600	H. P.
Haiwee	6,150	H. P.
San Francisquito	47,650	H. P.
San Fernando	9,685	H. P.
Total	72,885	

AQUEDUCT STATISTICS

BOND ISSUES.

1st Issue $1,500,000—40-year Bonds.

Voted Sept. 5, 1905, proportion 14 to 1.

Interest rate 4%.

Sold to local concerns at par.

Proceeds applied to purchase of lands and making of preliminary surveys.

2nd Issue $23,000,000—40-year Bonds.

Voted June 12, 1907, proportion 10 to 1.

Interest rate:	$ 1,033,600	at 4%
	21,964,000	at 4½%
	2,400	not issued.
	$23,000,000	

Total premium obtained, $94,256.33.

Sold as follows:

State of California	$ 510,000
Local Banks	510,000
Metropolitan L. I. Co.	500,000
New York Life I. Co.	500,000
Speyer & Co., N. Y.	2,890,000
Kountze Bros. and A. B. Leach & Co. with exception of few thousands, which were sold locally	18,087,600
	$22,997,600

Proceeds applied to construction work.

EXPENDITURES (Approx.)

Pay Rolls	$12,500,000
Freight and Express	2,250,000
Lands and R/W	1,700,000
Materials, Equipment and Miscl.	8,150,000
	$24,600,000

MAXIMUM MEN EMPLOYED.

May 11th to 20th, 1910, 3900 men.

MAXIMUM LIVE STOCK IN USE.

September, 1911:	Owned by City	755
	Rented	600
	Total	1355

MAXIMUM MONTHLY EXPENDITURES.

May, 1910, $575,000.

ESTIMATED SALVAGE.

Live stock, steam shovels, electrical and mechanical equipment, mining and concrete equipment, wagons, miscellaneous tools and equipment	$ 500,000
Power Plants and Transmission Lines	200,000
Cement Plant and Lands	550,000
	$1,250,000

CEMENT MILLS—OUTPUT.

	Bbls.
Monolith Mill, Portland cement	920,000
Fairmont Mill, Tufa, Regrind cement	280,000
Haiwee Mill, Tufa, Regrind cement	250,000
Total concrete used, approximately cubic yards.	1,500,000

LENGTH & SECTIONS OF THE AQUEDUCT.

		Capacity Sec. Ft.
Unlined Canal	21.1 miles	900
Open Lined Canal	39.5 miles	900
Haiwee By-Pass	2.0 miles	420
Covered Conduit	97.8 miles	420
Lined Tunnels	42.7 miles	420
Concrete Flumes	0.2 miles	420
Steel Siphons	9.3 miles	420
Concrete Siphons	2.8 miles	420
	215.4 miles	

		Capacity Sec. Ft.
Power tunnels, paid for jointly by Aqueduct and Power Bureaus	8.8 miles	1000
Reservoir	8.5 miles	
Total length, intake to lower end of last tunnel above San Fernando Reservoir	232.7 miles	

SIPHON STEEL.

Total tonnage, 15,000 tons.
Diameter of pipe, 7 feet 6 inches to 11 feet.
Thickness of plate, 1⅛ inch to ¼ inch.

WORK STARTED.

Elizabeth Tunnel, October, 1907.
Completed,—final, May, 1913.

PERSONNEL OF ORGANIZATION.

BOARD OF CONSULTING ENGINEERS.

Frederic P. Stearns of Boston, Mass.
John R. Freeman of Providence, R. I.
James D. Schuyler of Ocean Park, Cal.

BOARD OF PUBLIC WORKS.

1907:

James A. Anderson.
Albert A. Hubbard.
David K. Edwards.

1908-1912:

Albert A. Hubbard.
Lieut.-Gen. Adna R. Chaffee.
W. M. Humphreys.

1913:

Albert A. Hubbard.
Edward Johnson.
Lorin Handley.

ENGINEERING DEPARTMENT.

Executive:

Chief Engineer, Wm. Mulholland.

Assistant Chief Engineer, J. B. Lippincott.

Mechanical Constructor, Roderick MacKay.

Electrical Engineer, E. F. Scattergood.

Field Engineers:

Owens Valley, H. A. Van Norman.

Olancha, O. W. Peterson.

North Haiwee, W. P. Taylor.

South Haiwee, Phil Wintz.

Little Lake, Chas. H. Richards.

Grapevine, F. J. Mills.

Freeman, L. F. Mesmer.

Jawbone-Mojave, A. C. Hansen.

North Elizabeth, John Gray.

South Elizabeth, W. C. Aston.

Saugus, D. L. Reaburn.

Engineers Inspecting Line, 1906.

John R. Freeman — Jas. D. Schuyler — J. B. Lippincott — Fred P. Stearns — Wm. Mulholland

Rock Creek, a Tributary of Owens River in Round Valley.

Mt. Tom, in Sierra Watershed of Owens River.

Glacial Lake in Sierra Nevada.

Diversion Weir on Owens River at Aqueduct Intake.

Construction of Diversion Weir at Intake.

Beginning of the Aqueduct.

Raising Gates at Intake, Owens Valley.

Power House on Division Creek, Owens Valley.

Division Creek Power House No. 2.

Dredge in Open Canal, Owens Valley.

Boulders Removed by Steam Shovel From Conduit Line.

Hard Shoveling Along Alabama Hills Slope.

Steam Shovel at Work in Olancha Division.

Excavating Trench for Conduit.

Setting Forms for Concrete Lining, Alabama Hills Section.

Construction of Lined Canal Along Alabama Hills.

Lining Canal With Cement, Alabama Hills.

Engineers Inspecting Concrete Lined Canal, Alabama Hills.

Owens Lake as Seen from Line of Aqueduct.

Cement Lined Canal Along Slope 200 Feet Above Owens Lake.

Cottonwood Creek.

Cottonwood Power Plant and Conduit Near Owens Lake.

Cottonwood Creek Flume Across Conduit.

Electric Power Shovel Excavating for Conduit.

Excavation for Conduit Near Olancha.

A Mouthful of Rock—and Then Some.

Lined Canal and Railroad Crossing at Olancha.

Railroad Bridge Across Conduit at Olancha.

Lining the Conduit, Olancha Division.

Lined Canal Leading Into Haiwee Reservoir.

South Haiwee Dam in Process of Construction.

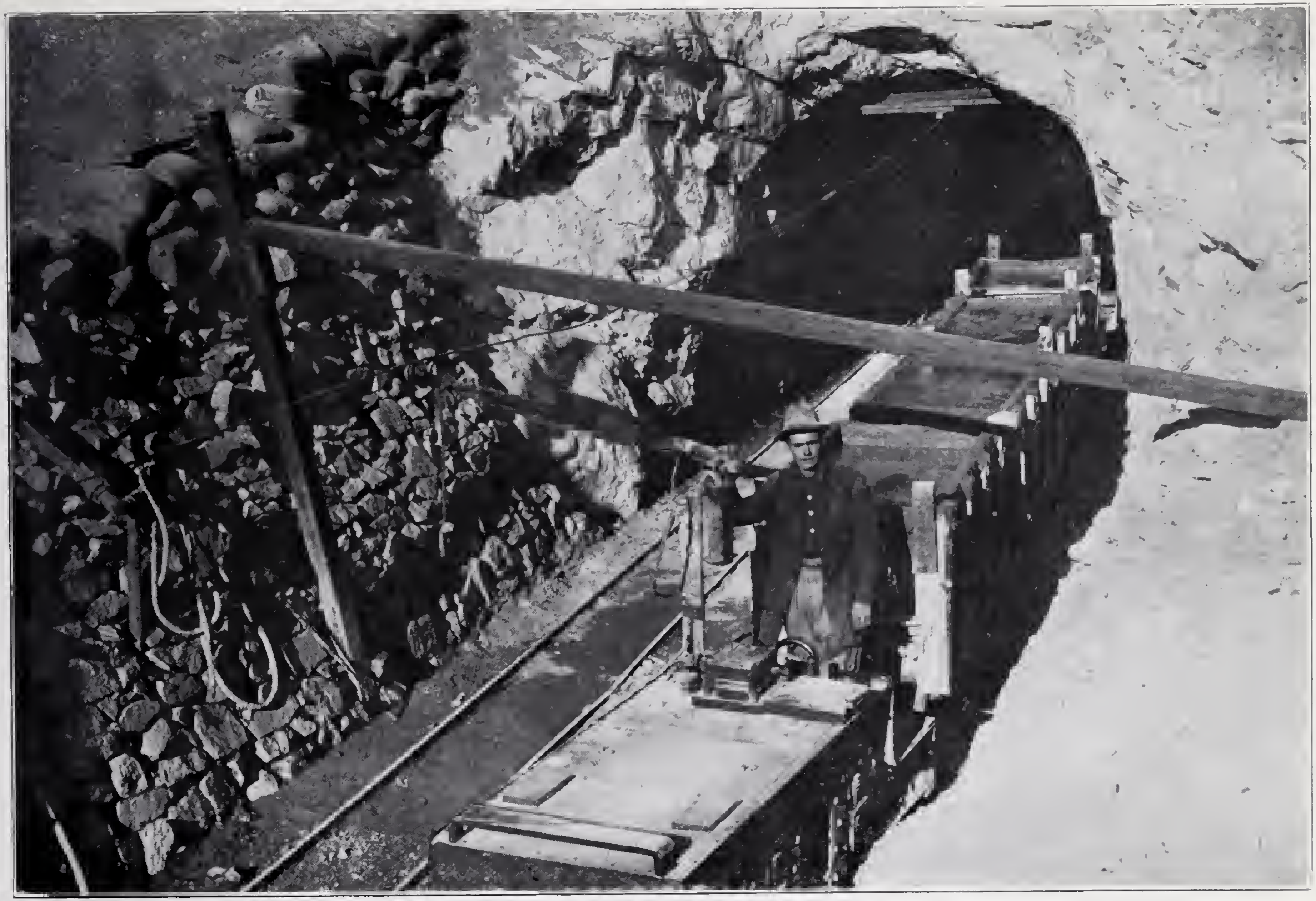
Building the Haiwee Dam.

Outlet From Haiwee Reservoir.

Setting Forms for Concrete Lining of Conduit.

Covered Conduit, Little Lake Division.

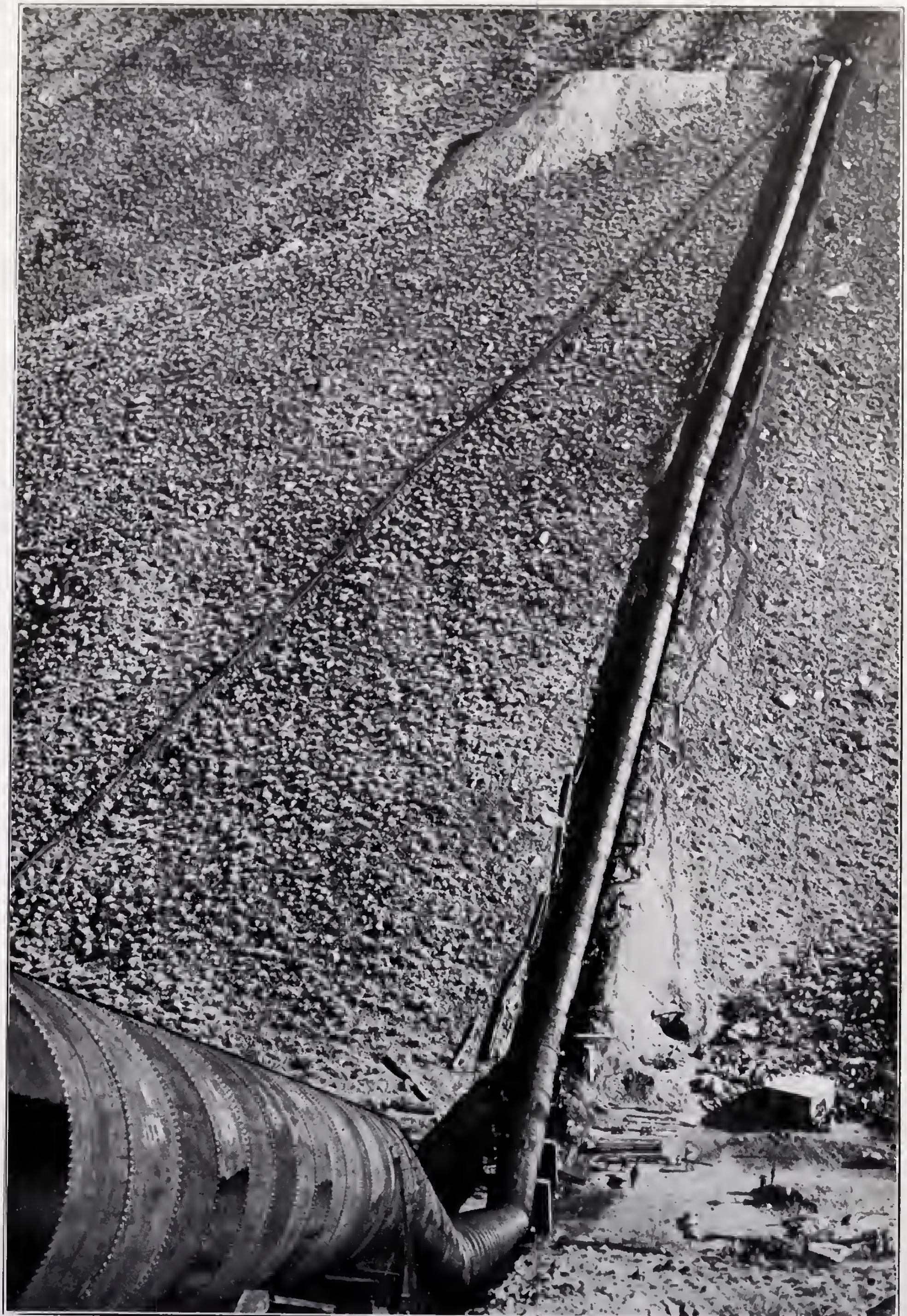
Covering Conduit With Concrete, Little Lake Division.



South End of Tunnel on North Side of Sand Canyon.

Engineers and Office Force at Sand Canyon.

Nine-Mile Canyon Siphon, Looking South.



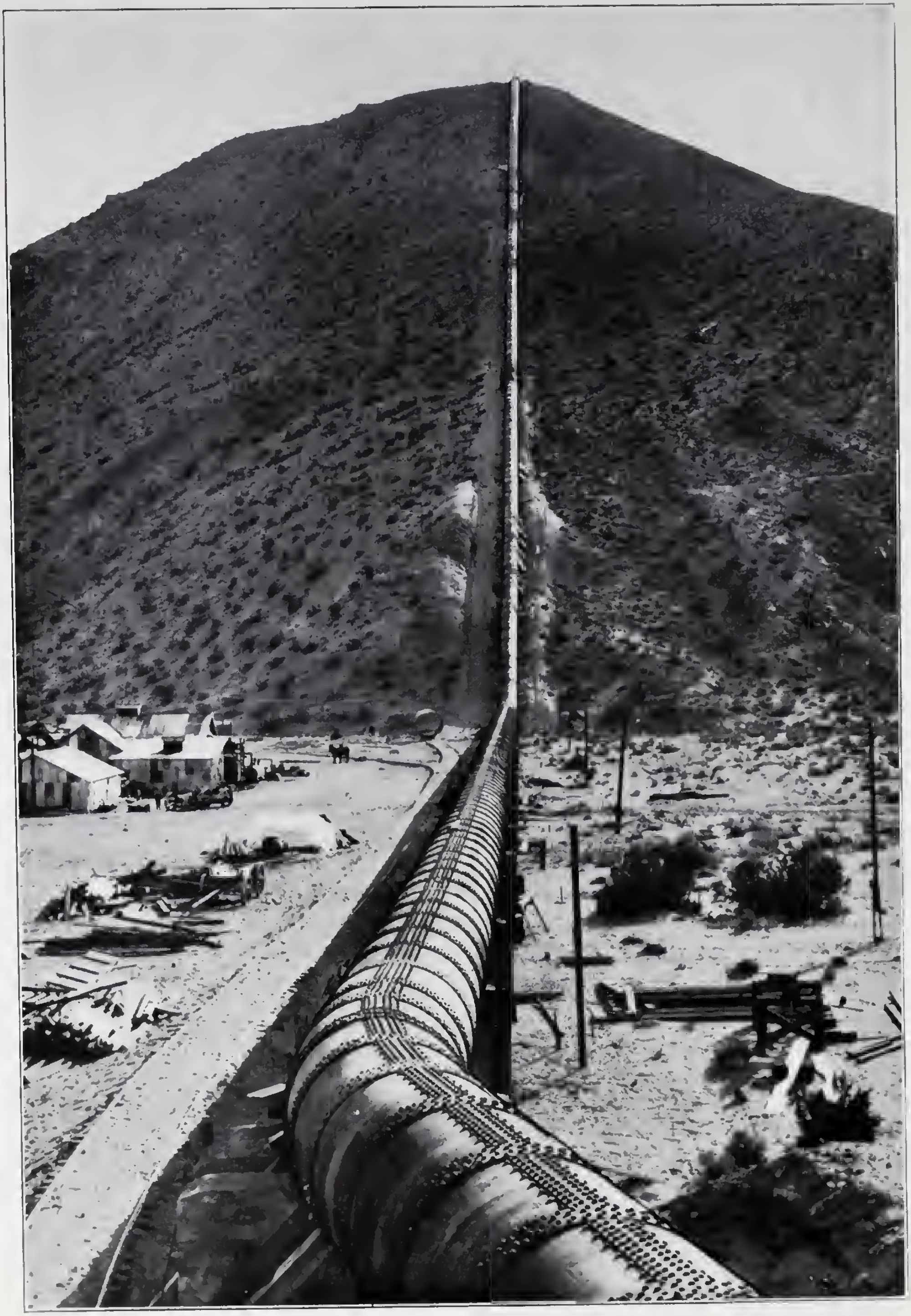
No-Name Canyon Siphon.

Concrete Flume Over Freeman Wash.

Sandstone Cliff in Red Rock Canyon.

Siphon Section Ready To Be Moved to Place.

Jawbone Siphon, Looking North.



Jawbone Siphon, Looking South.

Pine Canyon Siphon, Looking North.

Pine Canyon Siphon, North Side.

Forms for Concrete Conduit, Mojave Desert.

Commissary at Camp 2, Mojave Desert.

Hauling Siphon Pipe Forty Miles Across Mojave Desert.

Typical of Construction in Desert Sections.

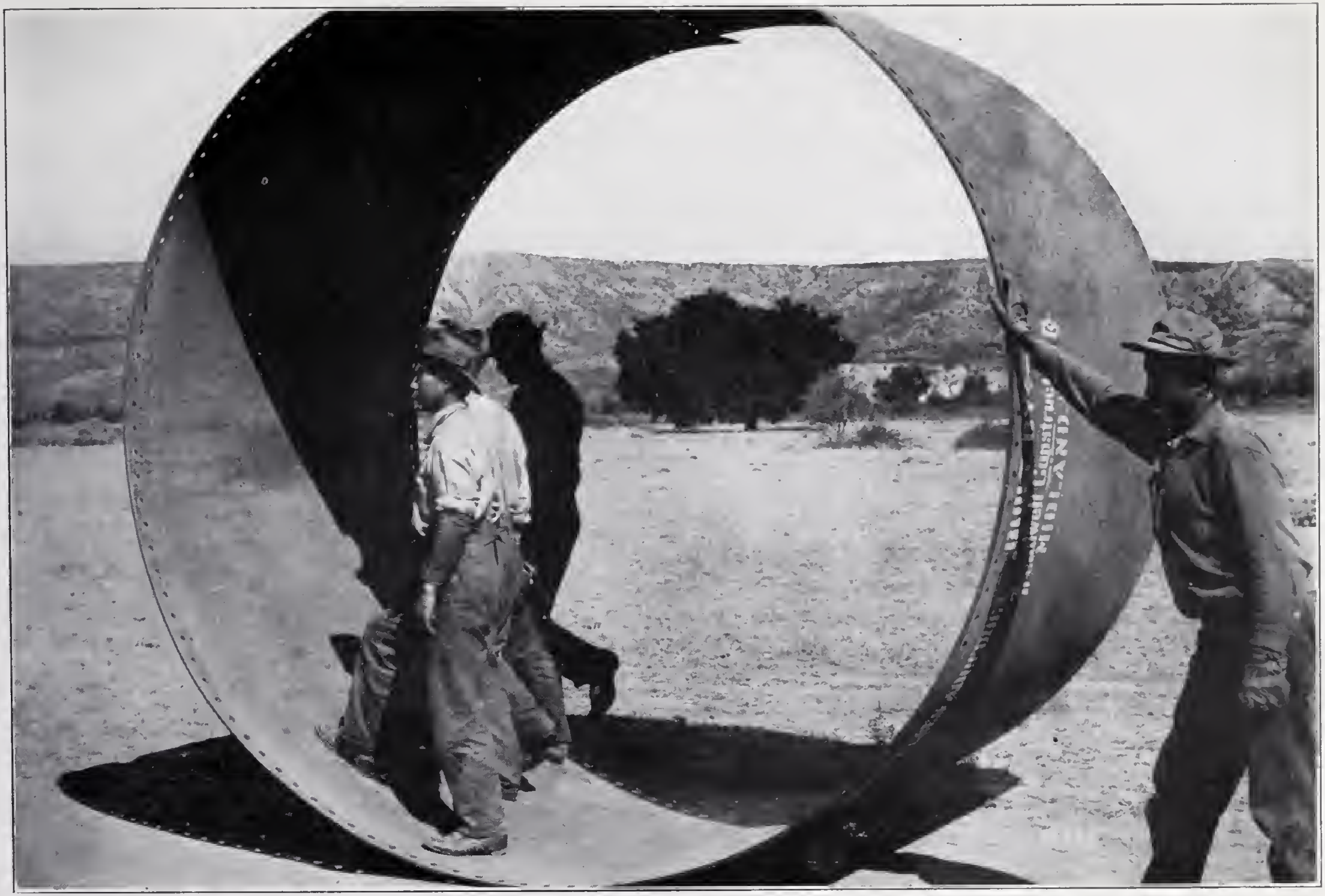
Yucca or "Joshua" Trees in Mojave Desert.

Forms for Cement Conduit Through Mojave Desert.

Cement Plant at Monolith.

Monolith Cement Mill.

Unloading Siphon Pipe From Car.



Section of Steel Siphon Pipe.

Section of Siphon Pipe.

Antelope Siphon as Auto Viaduct.

Concrete Forms for North End of Antelope Siphon.

Concrete Section of Antelope Siphon.

Antelope Valley Siphon.

Elizabeth Lake, Under Which Tunnel Was Driven.

Concrete Crew at North Portal Elizabeth Tunnel.

Concrete Crew at South Portal Elizabeth Tunnel.

Concrete Train at South Portal Elizabeth Tunnel.

Setting Forms for Concrete Tunnel Lining.

Forms for Concrete Lining in Place.

Tunnel Crew in Power Division, San Francisquito.

Portal of Power Tunnel, San Francisquito.

Forms for Cement Lining, Elizabeth Tunnel.

Commissary, San Francisquito.

Concrete Crew, San Francisquito Tunnel Adit.

John Gray In Portal of Power Tunnel.

Camp of Power Division, San Francisquito Canyon.

Location of Power House No. 1, in San Francisquito Canyon.

Road Built for Construction Purposes, San Francisquito.

Scene In San Francisquito Canyon.

Hauling Cement to Tunnel, Saugus Division.

Dry Canyon Dam From Reservoir Side.

Deadman Canyon Siphon, Looking South.

Deadman Canyon Siphon.

Constructing Concrete Piers for Soledad Siphon.

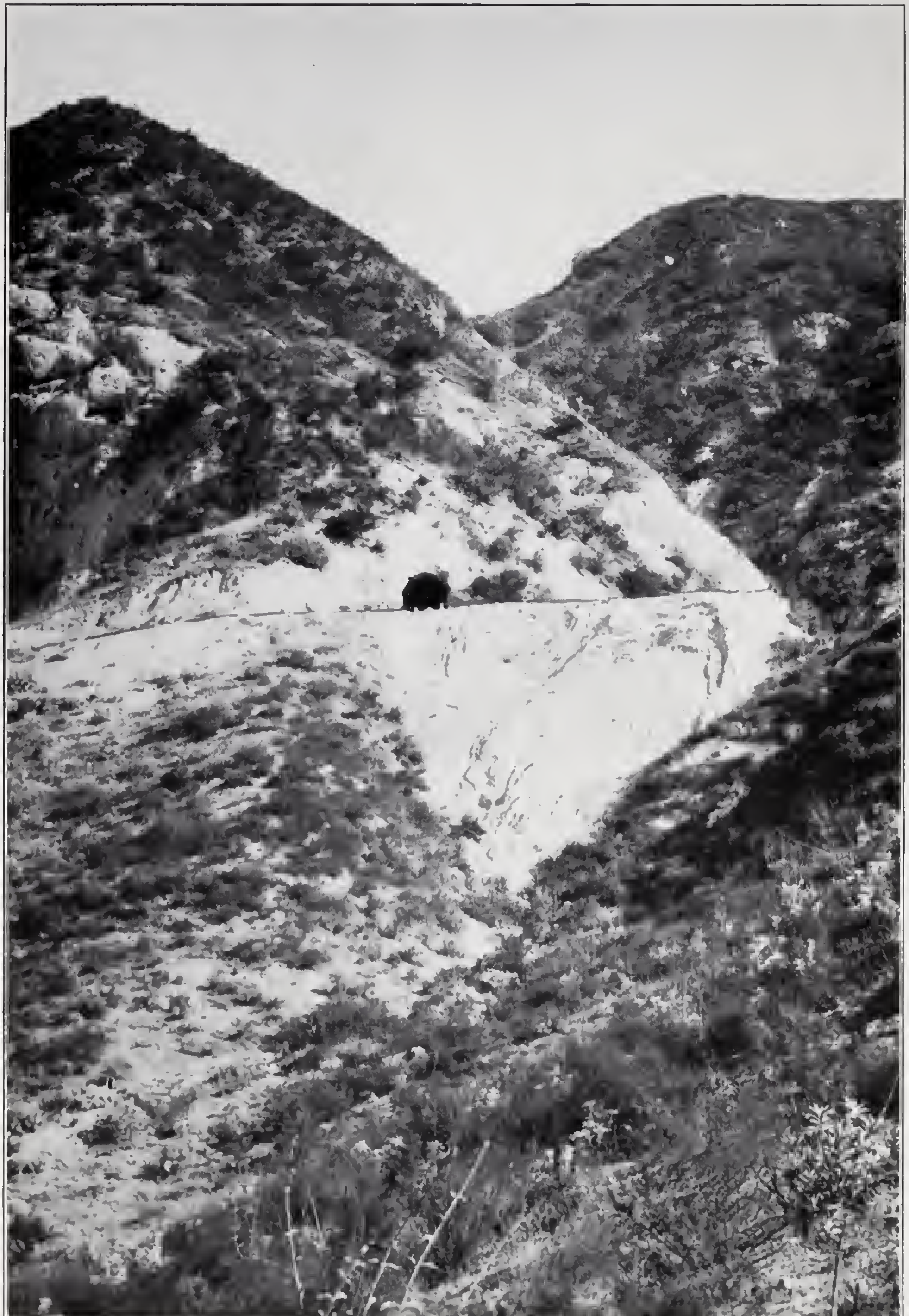
Soledad Siphon, Looking South.

North Half of Soledad Siphon.

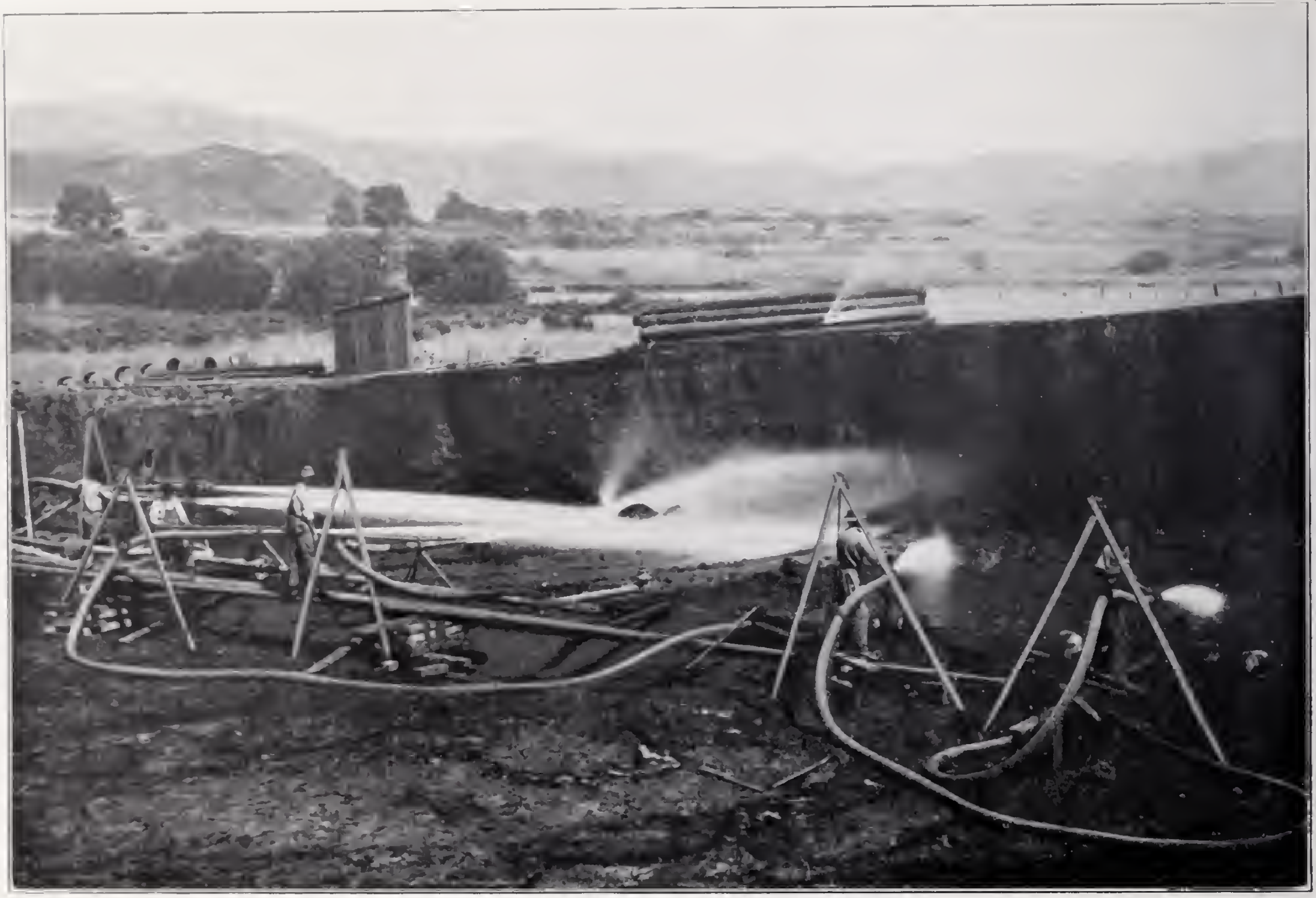
South Half of Soledad Siphon.

Soledad Siphon.

Tunnel in Saugus Division.



South Portal of Terminal Tunnel, San Fernando.



Building San Fernando Dam by Hydraulic Method.

Condult Under San Fernando Dam.

South Portal of Franklin Canyon Tunnel.

Engineers and Office Force at Narka.

Letting First Water Into Canal at Intake, Feb. 13, 1913.

Employes of City Water Department.